CONSERVATION OF ENERGY AND ECONOMIC ANALYSIS FOR PRODUCTION OF 50000 MT/ ANNUM TITANIUM DIOXIDE BY USING PINCH ANALYSIS

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ABSTRACT

Energy conservation techniques based on the Pinch Analysis is a way to minimize the energy consumption in production plant at the same time to maximize the process design. Pinch Analysis also enables the maximum interface between the utilities and process systems. Since no studies have been done on minimizing energy consumption in Titanium Dioxide Production Plant, there is a potential for energy conservation by using Pinch Analysis. The objectives of this research are to find the minimum energy requirement and to observe the effect of energy conservation to production cost and plant economics. In order to achieve the objectives, there are three main analysis are practiced which are Process Flow Diagram Analysis, Pinch Analysis and Economic Analysis. As the hot and cold stream was identified from the Process Flow Diagram, the thermal data extracted and recorded in a table. The value of ΔT min was selected between 5 to 25 °C. Next the Composite Curve and Grand Composite Curve were constructed based to the data extracted. The analysis then continued with the design of Heat Exchanger Network (HEN) where the HEN was designed at 5 different ΔT min value which are 5, 10, 15 20 and 25 °C. From HEN grid diagram analysis the minimum energy requirement can be determined and the analysis proceed with plant economic analysis that only focused to the heat exchanger and another cost that might affect after the Pinch was constructed. The results obtained from the earlier analysis are compared between the five different ΔT min to find the best. Overall analysis results in output where the best ΔT min equal to 15 °C with 50075.748 kW of energy required and a payback period of within one year of plant operation. The total cost is decreased by 35.36%.

ABSTRAK

Teknik kelestarian tenaga berasakan Analisa Cubitan merupakan satu cara untuk mengurangkan penggunaan tanaga dalam pelan penghasilan pada masa yang sama untuk memaksimakan reka bentuk proses. Analisa cubitan juga membolehkan peantaramukaan antara sistem utiliti dan proses. Memandangkan tiada lagi kajian dijalankan ke atas pengurangan tenaga dalam pelan menghasilkan *Titanium Dioxide,* kelestarian tenaga berpotensi dengan menggunakan Analisa Cubitan. Tujuan kajian ini adalah untuk mencari minimum tenaga yang diperlukan dan memerhatikan kesan kelesarian tenaga pelan penghasilan dan pelan ekonomi. Demi mencapai tujuan kajian tiga langkah utama telah di ambil iaitu Analisa Gambarajah Aliran Proses, Analisa Cubitan dan Analisa Ekonomi. Kelangsungan aliran panas an sejuk telah dapat ditemtukan daripada Gambarajah Aliran Proses, data termal diekstrak dan direkodkan dalam jadual. Nilai ΔT min dipilih di antara 5 hingga 25°C. Seterusnya lengkungan komposit dan lengkungan koposit utaa dibina berdasarkan data yang telah diekstrak. Penganalisaan kemudian diteruskan dengan merekabentuk Rangkaian Penukar Haba (HEN) di mana gambarajah kekisi HEN di rekabentukk pada lima ΔT min yang berlainan iaitu 5, 10, 15, 20 dan 25 °C. Daripada analisa gambarajah kekisi HEN minima tenaga yang diperlukan dapat dikenalpasti dan analisa ekonomi dan diteruskan dengan analisa ekonomi yang hanya fokus terhadap penukar haba dan kos lain yang terlibat setelah analisa cubitan dijalankan. Hasil analisis kemidian dibandingkan antara lima ΔT min yang demi mencari yang terbaik. Keseluruhan analisis meghasilkan ooutput dimana nila ΔT min terbaik adalah pada 15 °C dengan sebanyak 50075.748 kW tenaga diperlukan dan tempoh bayar balik selama satu tahun operasi. Jumlah kos berkurangan sebanyak 35.36%.

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LIST OF ABBREVIATIONS

CC	Composite Curve
COM	Cost of Manufacturing
DMC	Direct Manufacturing Cost
FCI	Fixed Capital Cost Investment
GCC	Grand Composite Curve
HEN	Heat Exchanger Network
PTA	Problem Table Algorithm

LIST OF SYMBOLS

ΔH	Different Enthalpy
ΔT or ΔT min	Different Temperature Minimum
ΔT_{lm}	Log Mean Different Temperature
ΔT_m	Different Mean Temperature
A_o	Provisional Area
A_t	Area of Tube
C_{GR}	Grass Root Cost
C_{OL}	Cost of Operating Labor
CP	Heat Capacity
CP_{cold}	Heat Capacity for Cold Stream
CP_{hot}	Heat Capacity for Hot Stream
C_{TM}	Total Module Cost
C_{UT}	Cost of Utilities
C_{WT}	Cost of Wastewater Treatment
D_i	Inlet Tube Diameter
D_o	Outlet Tube Diameter
D_s	Shell Diameter
DT or DT min	Different Temperature Minimum
F_T	Temperature Correction Factor for Heat Exchanger
L_t	Length of Tube
N_{cold}	Number of Cold Stream
N_{hot}	Number of Hot Stream
N_{np}	Number or non-particulate Processing Steps
N_{OL}	Number of Operators per Shift
Nt	Number of Tube
Q	Heat Flow or Heat Duty
T_{cin}	Cold Stream Inlet Temperature
T_{cout}	Cold Stream Outlet Temperature
T_{hin}	Hot Stream Inlet Temperature

T_{hout}	Hot Stream Outlet Temperature
T_s	Supply Temperature
T_t	Target Temperature
U	Heat Transfer Coefficient
W	Work

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CHAPTER 1

INTRODUCTION

1.1. Introduction

Nowadays, establishing minimum energy consumption for a maximum energy recovery becomes the most important roles in many process industries. Energy cost contributes significantly to the production cost. Hence, saving and optimizing the energy usage is a promise to meet the goal of an optimum energy cost and to be more profitability. As an addition, the energy reduction can give good environmental effect. This study focuses on energy conservation in the production of 50 000 MT/Annum titanium dioxide plant.

The consumption of utilities during the production can be very significantly large. Much work has been published on the design and optimization of utility systems. While some researchers advocate the use of heuristics and thermodynamics insight, others propose mathematical optimization (P. S. Varbanov *et al*, 2004)

Utilities have to develop and recommend integrated, reliable and cost effective approaches for meeting the future demand and energy needs. Changes in the national and local energy economy and business environment presents significant uncertainty and challenge. In order to manage effectively in this uncertain environment, utilities should place great emphasis on planning.

In order to achieve the energy conservation for a chemical plant, performing optimizing study on the heat exchanger is crucial, pinch analysis; a thermodynamics principles based that offers systematic approach to a optimum energy integration in a process will be performed, which will be examine at several different minimum temperature (ΔT min) in order to identify the best ΔT min that satisfy the energy recovery of the plant.

1.2. Research Background

This research is focused the study on conservation of energy and utilities usage in titanium dioxide plant. Titanium dioxide (TiO_2) exists in a number of crystalline forms which are anatase and rutile. The white pigment is used to give color to almost all materials. TiO_2 also provides opacity and brightness to plastics and rubber.

The production of 50 000 MTA Titanium Dioxide Plant has been planned to be located at Gebeng Industrial Estate. This plant operates based on chlorite process (US Pattern 6, 229, 037, 2001). Basically, the raw materials are synthetic rutile, chlorine gas, petroleum coke, and oxygen gas. There are 2 main reactions which are chlorination process and oxidation process. During chlorination process, synthetic rutile will reacts with chlorine gas to produce titanium tetrachloride vapor with chlorine gas as an excess reactant and for oxidation process, titanium tetrachloride will react with oxygen gas to produce titanium dioxide powder.

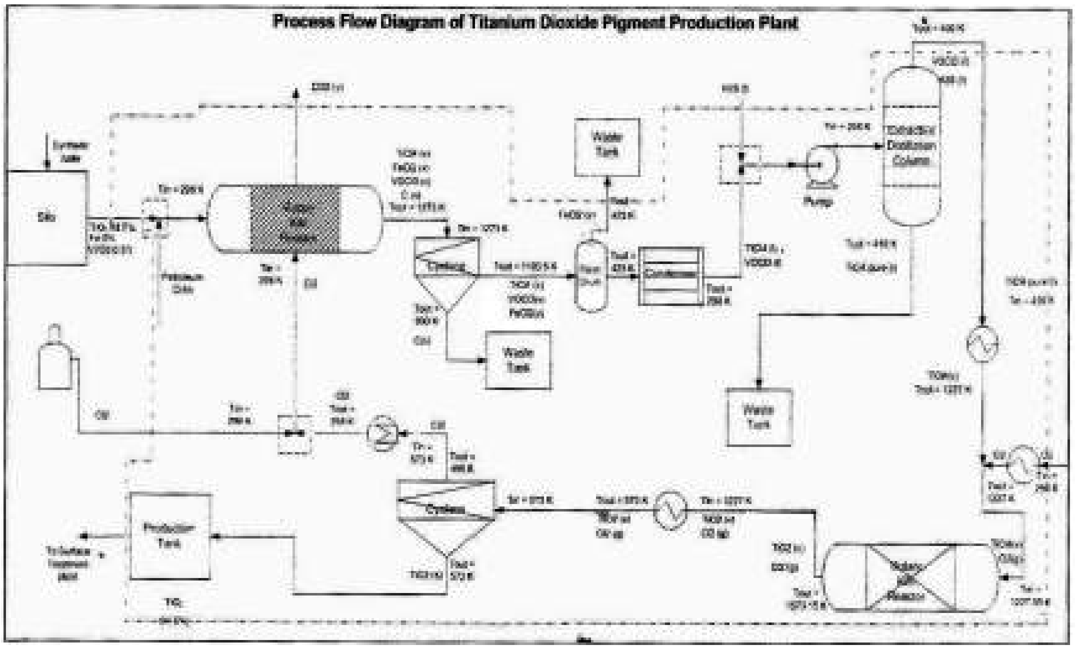


Figure 1.1: Process Flow Diagram (PFD) of Titanium Dioxide Production Plant

For the purpose of producing 50 000 MT per annum, the plant has a silo, three storage tanks, two rotary kiln reactors, two cyclones, a flash drum, a condenser, a pump, an extractive distillation column, 4 heat exchangers and a production tank for storage. There are three hot streams and two cold streams, which need utilization of energy.

The purpose of the silo is for raw material of synthetic rutile storage before undergoing the production process of Titanium Dioxide. Synthetic rutile in solid form stored in the silo at the beginning of the process at atmospheric pressure. The silo stores the synthetic rutile for daily start up process that is sufficient enough for 24 hours.

One of the storage tanks is for the raw material of petroleum coke storage before mixed with synthetic rutile at the mixing point. The second storage tank is for storing oxygen gas before entering reactor for combustion process. The oxygen gas is stored in gaseous form at room temperature and standard environmental pressure. The other storage tank is to store chlorine gas that needed to make sure oxygen supply sufficient for every reaction in rotary kiln 1 for combustion process. All of the storage tanks are also stores product for daily needs of process.

Cyclone is used for gas – solid separation process for gas cleaning; to remove dispersed finely divided solid (dust) and liquid mist from gas stream. Process gas must be cleaned up to prevent contamination of catalyst or product, and to avoid damage to equipment such as compressor. Flash column is used for separation of two phase mixture such as vapor – liquid mixture. The separation of the different phases of a heterogeneous mixture should be carried out before homogeneous separation.

Both heat exchanger and condenser are used to transfer the heat between two fluids. The transfer of heat is accomplish from the hot fluid to the wall or tube surface by convection, through the tube wall or plate by conduction and then by convection to the cold fluid.

The basic concept of a heat exchanger is based on the premise that the loss of heat on the high temperature side is exactly the same as the heat gained in the low temperature side after the heat and mass flows through the heat exchanger. (www.heatexchangersgamma.com)

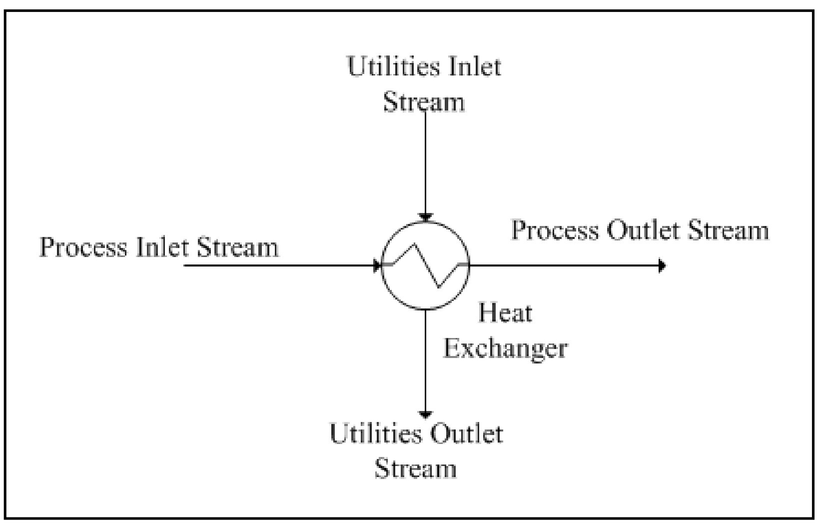


Figure 1.2: Heat Exchanger Streams Flow

Figure 1.2 shows both process stream and utility stream in the heat exchanger. As the temperature in the process streams is needed to be increase or decrease, the utility streams will provide the medium for heat transfer to occur.

The overall energy usage in the heat exchanger is summarized in the following table:

Table 1.1: Energy Usages of the Heat Exchangers

No. of heat exchanger	**Product**		**Utility stream**		**Energy (kW)**
	T_{in} (°C)	**T_{out} (°C)**	**T_{in} (°C)**	**T_{out} (°C)**	
Heat exchanger 1	137	954	234	981	-92.62
Heat exchanger 2	25	954	246	981	41870.00
Heat exchanger 3	954	300	100	410	12720.00
Heat exchanger 4	300	25	10	137	-3284.00
Condenser	150	25	10	20	-1215.00

Along with the overall energy consumption information as shown in Table 1.1 above also include both products and utilities' inlet and outlet temperature for each of the heat exchangers and condenser.

The utility must develop its best estimate of growth in future demand and energy requirement for their customers. Because of the uncertain nature of this forecast, utilities define reasonable upper and lower bounds of potential growth. (A. S Farag *et al*, 1999)

1.3. Problem Statement

The main purpose of business is to gain profit. Changes in the national and local energy economy and the business environment present significant uncertainties and challenges. In order to manage this uncertain environment, utilities usage should have great planning. The energy plan should be considerate with the overall operating expense requirement of the utilities to ensure the ongoing great financial management.

The overall heat exchanger and utilities usage costing in the plant is summarized in the following table.

Table 1.2: Overall Heat Exchanger Costing

Equipment	Bare Module Equipment Cost (RM)
Heat Exchanger 1	359,936.00
Heat Exchanger 2	899,480.00
Heat Exchanger 3	1,012,320.00
Heat Exchanger 4	501,098.40
Condenser	140,692.83

Table 1.3: Overall Utilities Usage and Costing

Utility	Usage	Operation (hr/yr)	Cost (RM/yr)
Electricity	15633.44 kW	8322	25,760,098.13
Water	2201.665 m^3/hr	8322	15,390,695.15

The water consumption shows above is the 5% of water consumed in the first run of operation. The plant has high cost in heat exchanger installation and its utilities usage. As the plant is yet to be optimized, the production cost has potential to be reduced.

1.4. Objectives

The objectives of the study are as follows:

1.4.1. To find minimum energy requirement of the plant.

1.4.2. To observe the effects of energy conservation to the production cost and plant economics

1.5. Scope of Study

In order to achieve the objectives the scope of the study are identified as follow:

1.5.1. Process Flow Diagram (PFD)

To identify potential energy recovery from hot stream and cold stream of Titanium Dioxide plant stream data.

1.5.2. Heat exchanger and stream data

To study the energy requirement for all heat exchangers with the respective stream data.

1.5.3. Pinch Point Analysis

Performing Pinch Point Analysis to every heat exchanger to determine the target of energy saving.

1.5.4. Production Cost and Economics Analysis

Production cost is the combination of raw material cost and labor incurred in producing goods, but for this research it will be focused on utility cost instead of the raw material cost.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

This chapter will focused on the explanation of Pinch Analysis and its principles as well as further insight and investigation into previous research about energy conservation and its effect to the plant economics.

Heat exchanger network design may depend on the heat pinch targeting stage in an approach whereby the hot and cold composite curves (CCs) are used to determine the heat energy targets (heat recovery, cold utility, and hot utility) at a specified minimum temperature differential DTmin (R. Smith, 1995)

Pinch Technology is a tool for optimization of a plant's heat recovery. Pinch Analysis application requires extensive process mass and energy balance data and are able to provide engineers with a systematic approach to improve heat recovery in a process through optimal exchange of heat at the appropriate temperature levels. Since its inception during the late 60s, Pinch Technology has been applied successfully optimization of energy usage in the chemical process industries, resulting it up to 90% energy and 25% capital saving said by Linholf B *et al*, (1982) (Zainuddin Abul Manaf & Foo Sheek Hia, 2000)

Great economic and energy savings were realized by the pinch analysis in comparison to the existing plant. In order to produce new Heat Exchanger Network

(HEN), the capital cost had to be increase but the total cost trade-off between the capital and energy cost will be decrease by 30% (Mirjana Kijevčanin *et al.* 2004)

2.2. Pinch Analysis

Pinch technology, methodology of analyzing heat use, has progressed since it was first developed in the 1970s onwards at the ETH Zurich and Leeds University (Linholf and Flower 1978; Linholf, 1979). ICI plc took note of these promising techniques and set up research and applications teams to explore and develop them (Ian C Kemp., 2007).

A Pinch Analysis starts with the heat and material balance for the process. Using Pinch Technology, it is possible to identify appropriate changes in the core process conditions that can have an impact on energy savings (onion layers one and two).

The onion layer is the process design hierarchy that can be represented by the "onion diagram" as shown below. The design of a process starts with the reactors (in the "core" of the onion). Once feeds products, recycle concentrations and flow rates are known, the separators (the second layer of the onion) can be designed. The basic process heat and material balance is now in place, and the heat exchanger network (the third layer) can be designed. The remaining heating and cooling duties are handled by the utility system (the fourth layer). The process utility system may be a part of a centralized site-wide utility system.

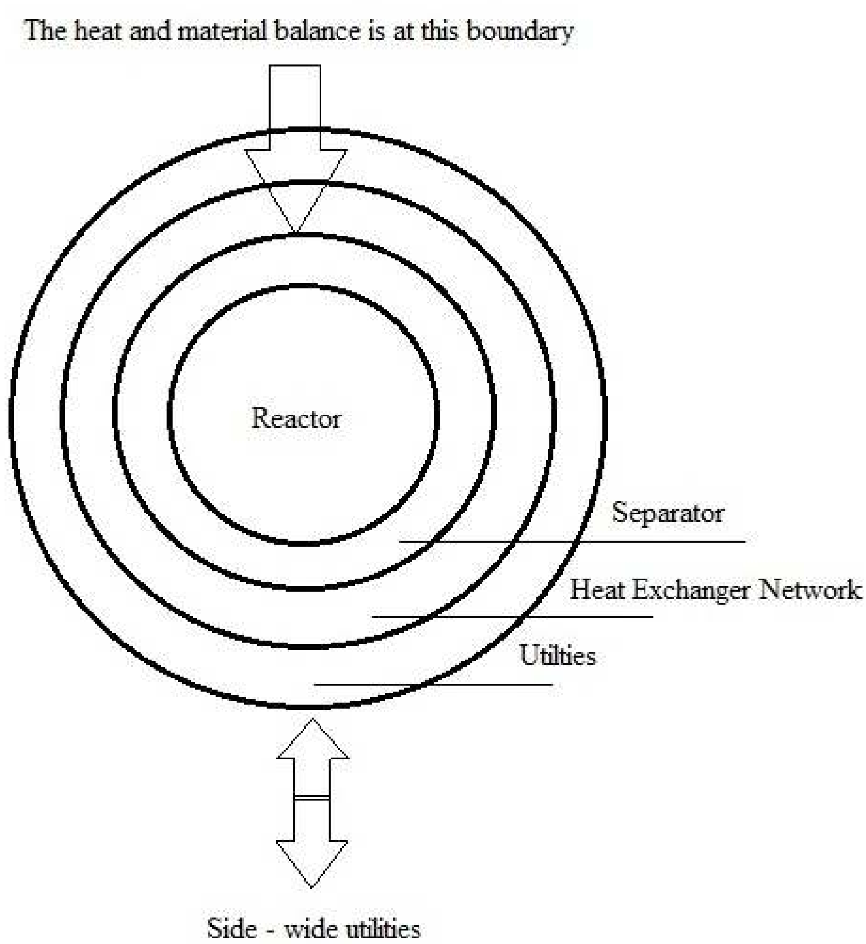


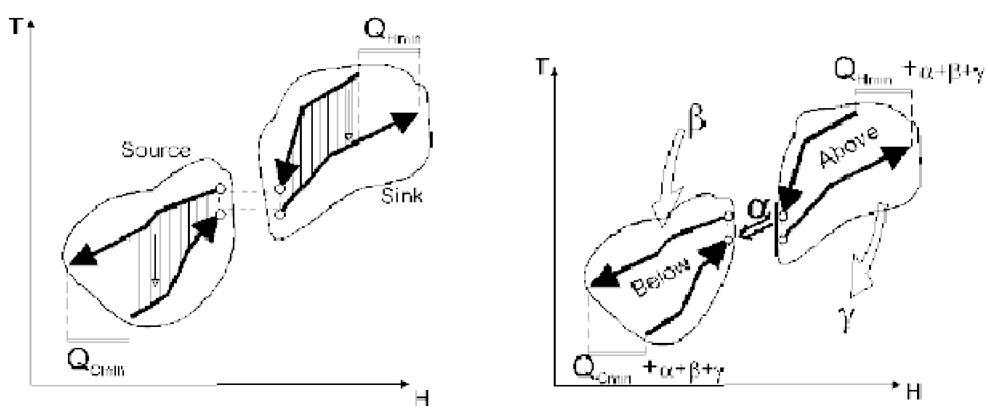
Figure 2.1: The “Onion Diagram” of Hierarchy of Process Design

After the heat and material balance is established, targets for energy saving can be set prior to the design of the heat exchanger network. The Pinch Design Method ensures that these targets are achieved during the network design. Targets can also be set for the utility loads at various levels (e.g. steam and refrigeration levels). The utility levels supplied to the process may be a part of a centralized site-wide utility system (e.g. site steam system). Pinch Technology extends to the site level, wherein appropriate loads on the various steam mains can be identified in order to minimize the site wide energy consumption. Pinch Technology therefore provides a consistent methodology for energy saving, from the basic heat and material balance to the total site utility system.

One tool in the area-wide pinch technology analyzes the transfer of heat among the energy systems of an industrial area (among multiple plants). This can show that there is excess heat recovered from the exhaust heat that can be given to the heat demand side, which will lead to energy saving (Chiyoda Corporation, External Affairs Section).

2.2.1. The Pinch Principles

The point where DT min is observed is known as the "Pinch" and recognizing its implications allows energy targets to be realized in practice. Once the pinch has been identified, it is possible to consider the process as two separate systems: one above and one below the pinch, as shown in figure below. The system above the pinch requires a heat input and is therefore a net heat sink. Below the pinch, the system rejects heat and so is a net heat source.



i. The Pinch divides the problem into source and sink	ii. By violating the three golden rules Q_{Hmin} and Q_{Cmin} are each increase by $\alpha + \beta + \gamma$

Figure 2.2: The Pinch Principles

In Figure (ii), an amount of heat is transferred from above the pinch to below the pinch. The system above the pinch, which was before in heat balance with Q_{Hmin}, now loses a unit of heat to the system below the pinch. To restore the heat balance, the hot utility must be increased by the same amount, that is, a unit. Below the pinch, a unit of heat is added to the system that had an excess of heat, therefore the cold utility requirement also increases by a units. In conclusion, the consequence of a cross-pinch heat transfer (i) is that both the hot and cold utility will increase by the cross-pinch duty (i).

To summarize, the understanding of the pinch gives three rules that must be obeyed in order to achieve the minimum energy targets for a process:

i. Heat must not be transferred across the pinch
ii. There must be no external cooling above the pinch
iii. There must be no external heating below the pinch

Violating any of these rules will lead to cross-pinch heat transfer resulting in an increase in the energy requirement beyond the target. The rules form the basis for the network design procedure which is described in Heat Exchanger Network Design. The design procedure for heat exchanger networks ensures that there is no cross pinch heat transfer. For retrofit applications the design procedure "corrects" the exchangers that are passing the heat across the pinch.

2.2.2. Pinch Effect to Plant Economic Saving

BASF, Germany, reported completing over 150 projects and achieving site-wide energy saving of over 25% in retrofits in their main factory in Ludwigshafen (Korner 1988). Based from existing research, the Energy and economy savings in the process of methanol synthesis using Pinch technology an important aspect of energy